chapter

9 Respiratory System and Motor System

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Top water polo players are superb athletes. The sport requires the strength of a rower, the endurance of a cross-country skier, and the scoring touch of a soccer player.

What separates athletes, like Waneek Horn-Miller, an Aboriginal athlete (**Figure 1**), from the majority of us? The exceptional physical fitness of an athlete depends largely on the superior ability to deliver oxygen and chemical fuels to the cells of the body. To sustain life-giving processes, all cells require nutrients and oxygen. Within the mitochondria inside the cells, oxygen is used during cellular respiration to convert organic chemicals to energy-rich ATP molecules that fuel cellular activities. In muscle cells, this energy is used for movement. Athletes also often have a superior respiratory system that provides an excellent exchange of air, ensuring plentiful oxygen for the cells.

Training can increase your ability to take in oxygen (through the respiratory system) and deliver it (through the circulatory system) to cells of the body. Training can also change the amount of muscle tissue in your body, while inactivity can cause the amount of muscle tissue to shrink.

However, not everyone who trains will become an elite athlete. Your inherited physiology may not allow for sufficient ventilation for you to excel in one sport, but may make you better suited for a different sport or activity.

In this chapter, you will first look at the respiratory system and how it works to deliver oxygen to the cells. Then, you will look at the muscles in the human motor system. The motor system supports all the systems of the human body, including the respiratory system and digestive system you read about in the previous chapter.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. What everyday experiences indicate the importance of providing oxygen to living cells?
2. Fitness can be measured by the body's ability to provide oxygen for the tissues of the body. Make a list of sports that you believe require great fitness. Make another list of sports that you believe require less fitness. Be prepared to justify your answers.
3. Predict how changes in oxygen level might affect muscle activity.

Career Connections:
Physiologist; Commercial Diver; Prosthetist and Orthotist

Figure 1
Waneek Horn-Miller led Canada's women's national water polo team in the 2000 Olympics in Sydney.

Exploration — Making a Model of the Chest Cavity

You can make a model of the human chest cavity. The balloons represent the lungs, and the latex glove represents the diaphragm.

Materials: empty 2-L plastic bottle, two balloons, Y-tube, rubber stopper with hole, latex surgical glove, elastic band, scissors

- Cut the bottom off the plastic bottle.
- Place the rubber stopper into the neck of the bottle.
- Place a balloon over the two ends of the Y-tube.
- Insert the Y-tube and balloons into the bottle. Twist the free end of the Y-tube into the hole in the rubber stopper.
- Stretch the glove over the bottom of the bottle and secure with the elastic band (**Figure 2**).

(a) Predict what will happen when you pull down and then push up on the glove. Test your prediction.

(b) Relate your observations to air pressure in the model.

(c) How could you improve the model?

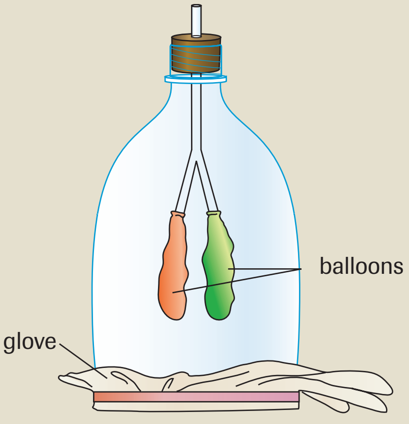


Figure 2
Model of chest cavity

9.1 The Importance of an Oxygen Delivery System

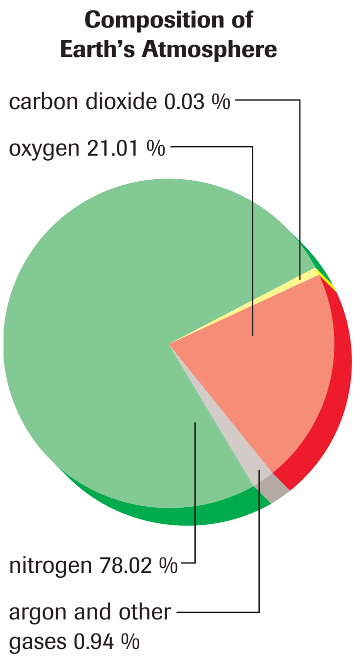


Figure 1
Nitrogen and oxygen are the two most abundant components in atmospheric air.

You live in a sea of air. Nitrogen, oxygen, carbon dioxide, and trace gases are taken into and expelled from your body with every breath. Earth's atmosphere is made up of approximately 78 % nitrogen and 21 % oxygen; the remaining gases, argon, carbon dioxide, and others, make up about 1 % (**Figure 1**). The second most abundant component, oxygen, is vital to life. Cells obtain energy through a chemical reaction called oxidation, in which organic compounds are broken down using oxygen. Although a small amount of energy can be obtained in anaerobic conditions (in the absence of oxygen), life processes in humans cannot be maintained without an adequate supply of oxygen.

Oxygen is so essential to the survival of humans that just a few minutes without it will result in death. By comparison, individuals can live for a number of days without water and several weeks without food. It has been estimated that an average adult utilizes 250 mL of oxygen every minute while resting. Oxygen consumption may increase up to 20 times with strenuous exercise.

Respiration and Breathing

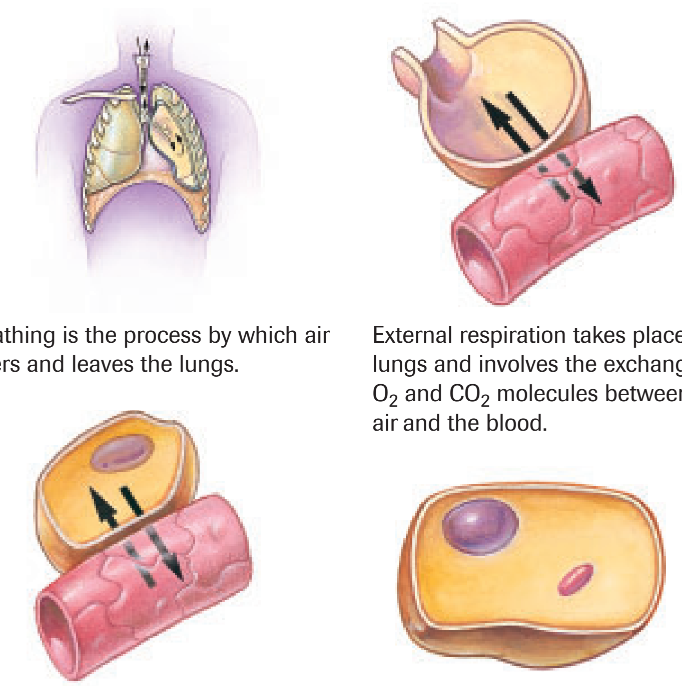
Breathing, or ventilation, involves the movement of air between the external environment and the body. The uptake of oxygen and the release of carbon dioxide by cells take place across a **respiratory membrane**.

The term **respiration** can be used to describe all processes that supply oxygen to the cells of the body for the breakdown of glucose and to describe the process by which carbon dioxide is transported to the lungs for exhalation. **Figure 2** shows the processes involved in respiration.

breathing the process of the exchange of air between the lungs and the environment, including inspiration and expiration

respiratory membrane the membrane where the diffusion of oxygen and other gases occurs between the living cells of the body and the external environment (the atmosphere or water)

respiration all processes involved in the exchange of oxygen and carbon dioxide between cells and the environment, including breathing, gas exchange, and cellular respiration



Breathing is the process by which air enters and leaves the lungs.

External respiration takes place in the lungs and involves the exchange of O_2 and CO_2 molecules between the air and the blood.

Internal respiration takes place within the body and involves the exchange of O_2 and CO_2 molecules between the blood and tissue fluids.

Cellular respiration involves the production of ATP in body cells.

Figure 2
The processes of respiration

Oxygen is used for cellular respiration. Organelles called mitochondria are the centres of cellular respiration. During the process of cellular respiration, oxygen and sugar molecules react, resulting in the production of carbon dioxide and water. The energy released is used to maintain cell processes, such as growth, movement, and the creation of new molecules. The concentration of oxygen in cells is much lower than in their environment because cells continuously use oxygen for cellular respiration. Oxygen must be constantly replenished if a cell is to survive.

Practice

1. Why is oxygen so essential for survival?
2. Differentiate between breathing and cellular respiration.
3. What is the function of the respiratory membrane?

The Human Respiratory System

In humans, air enters the respiratory system either through the two nasal cavities or the mouth (**Figure 3**). Foreign particles are prevented from entering the lower respiratory tract by tiny hairs lining the nasal cavities that act as a filtering system. The nasal cavities warm and moisten incoming air and contain mucus, which traps foreign particles and keeps the cells lining the cavities moist.

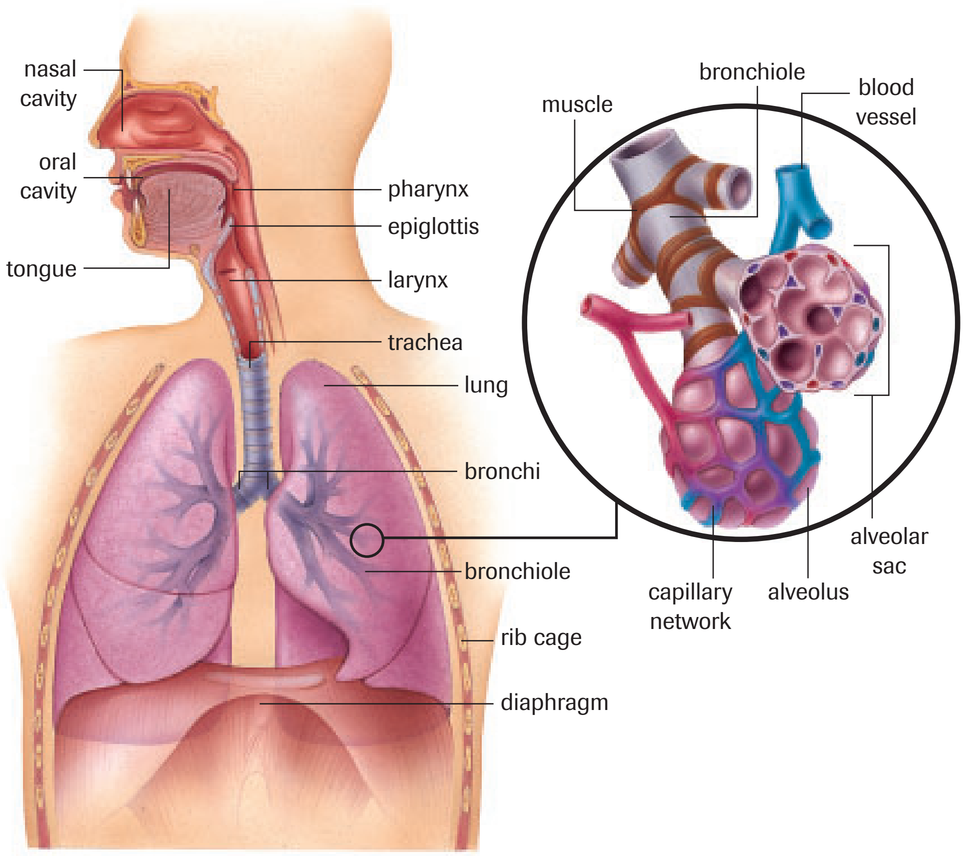


Figure 3
The human respiratory system

CAREER CONNECTION

Physiologist

Physiologists study the functions of cells, organs, tissues, and their interrelationships. There are many specializations in physiology, including exercise physiology, which studies how the body responds to exercise. Physiologists may work in a laboratory, or they may teach. What education is required to become a physiologist? Explore further to find examples of the type of work physiologists do.

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EXTENSION

Structure of an Alveolus

This animation provides a cutaway view of an alveolus and takes a closer look at the respiratory membrane which separates the capillaries from the alveoli.

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trachea the windpipe

cilia tiny hairlike structures found on some cells that sweep away foreign debris

epiglottis the structure that covers the glottis (opening of the trachea) during swallowing

The nasal cavities open into an air-filled channel at the back of the mouth called the pharynx. Two openings branch from the pharynx: the **trachea**, or windpipe, and the esophagus, which carries food to the stomach. Mucus-producing cells, some of which are ciliated, line the trachea. The mucus traps debris that may have escaped the filters in the nasal passage. This debris is swept by the **cilia** (singular: cilium) from the windpipe back into the pharynx. The wall of the trachea is supported by bands of cartilage, which keep the trachea open. An enlarged segment of cartilage (the larynx) supports the **epiglottis**, a flaplike structure that covers the glottis, or opening of the trachea, when food is being swallowed. When food is chewed, it is forced to the roof of the mouth and pushed backward. This motion initiates a reflex action, which closes the epiglottis, allowing food to enter the esophagus rather than the trachea. If you have ever taken in food or liquids too quickly, you will know how it feels to bypass this reflex. Food or liquid entering the trachea stimulates the cilia, and particles too large to be swept out of the respiratory tract are usually expelled by a second more powerful reflex: a violent cough.

larynx the voice box

Air from the pharynx enters the **larynx**, or voice box, located at the upper end of the trachea. The larynx contains two thin sheets of elastic ligaments that form the vocal cords (**Figure 4**). The vocal cords vibrate as air is forced past them. Different sounds are produced by a change in tension on the vocal cords. Your larynx is protected by thick cartilage commonly known as the Adam's apple. Following puberty, the cartilage and larynx increase in size and thickness, more so in males than females. In the same way as a larger drum creates a lower-pitched sound, the larger voice box in males produces a deeper sound. Rapid growth of the larynx creates problems for adolescent boys, who have difficulty controlling the pitch of their voices. Have you ever noticed how your voice lowers when you have a cold? Inflammation of the vocal cords causes swelling and produces lower-frequency vibrations. Should the infection become severe and result in a condition referred to as laryngitis, you may temporarily lose your voice.

DID YOU KNOW?

What Are Hiccups?

All of us have had the hiccups at one time or another. An irritation of the diaphragm causes air to become trapped in the respiratory tract and the diaphragm experiences a muscular spasm. The hiccup sound is produced when air is taken in as the glottis closes.

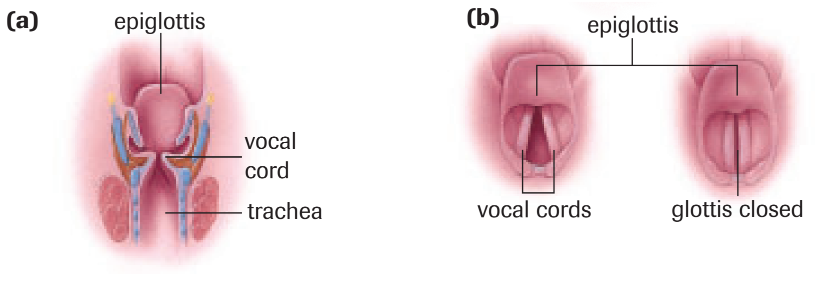

Figure 4

(a) Larynx, showing the vocal cords

(b) Position of the vocal cords when the glottis is open and closed during speech

bronchi the passages from the trachea to the left and right lung

bronchiole the smallest passageways of the respiratory tract

alveoli sacs of the lung in which gas exchange occurs

Inhaled air moves from the trachea into two **bronchi** (singular: bronchus), which, like the trachea, contain bands of cartilage. The bronchi carry air into the right and left lungs, where they branch into many smaller airways called **bronchioles**. Unlike the trachea and bronchi, the bronchioles do not contain cartilaginous bands. Muscles in the walls of the bronchioles can decrease their diameter. Any closing of the bronchioles increases the resistance of air movement and can produce a wheezing sound. Air moves from the bronchioles into tiny sacs called **alveoli** (singular: alveolus). Measuring between 0.1 and 0.2 μm (micrometres) in diameter, each alveolus is surrounded by capillaries. In the alveoli, gases diffuse between the air and blood according to concentration gradients. Oxygen and carbon dioxide both move from areas of higher concentration to areas of lower concentration. Therefore, oxygen moves from the air within alveoli into the capillaries, while carbon dioxide moves from the capillaries into the air in the alveoli. The

alveoli are composed of a single layer of cells, which permits rapid gas exchange. (However, the respiratory membrane is really three layers thick.) Each lung contains about 150 million alveoli. That provides enough surface area to cover half a tennis court, or about 40 times the surface area of the human body.

Have you ever tried to pull the cover slip from a microscope slide, only to discover that it seems to be fused to the slide? This phenomenon is caused by water molecules adhering to the glass. A similar problem faces the alveoli. During inhalation the alveoli appear bulb shaped, but during exhalation the tiny sacs collapse. The two membranes touch but are prevented from sticking together by a film of fat and protein called lipoprotein. This film lines the alveoli, allowing them to pop open during inhalation. Some newborn babies, especially premature babies, do not produce enough of the lipoprotein. Extreme force is required to overcome the surface tension created, and the baby experiences tremendous difficulty inhaling. This condition, referred to as respiratory distress syndrome, often results in death.

The outer surface of the lungs is surrounded by a thin membrane called the **pleural membrane**, which also lines the inner wall of the chest cavity. These two membranes adhere to each other. This adhesion is why the lungs expand and draw in air when the volume of the chest cavity is increased. The space between the pleural membranes is filled with a small amount of fluid that reduces the friction between the lungs and the chest cavity during inhalation. Pleurisy, the inflammation of the pleural membranes, is most often caused by a viral infection or pneumonia. The inflammation may result in friction of the membranes. Sometimes, fluid builds up between the pleural membranes. This buildup of fluid puts pressure on the lungs, making expiration (exhalation) easier, but inspiration (inhalation) much more difficult and painful.

EXTENSION

Maintaining the Alveolar Space

Why do the alveoli in your lungs stay expanded? This Audio Clip will explore the factors that prevent the alveoli from collapsing.

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pleural membrane a thin membrane that surrounds the outer surface of the lungs and lines the inner wall of the chest cavity

Practice

4. Describe the function of cilia in the respiratory tract.
5. Explain how the functions of the trachea, esophagus, and epiglottis are related.

Breathing Movements

Pressure differences between the atmosphere and the chest, or thoracic, cavity determine the movement of air into and out of the lungs. Atmospheric pressure remains relatively constant, but the pressure in the chest cavity may vary. An understanding of breathing hinges on an understanding of gas pressures.

Gases move from an area of high pressure to an area of low pressure. Inspiration occurs when pressure inside the lungs is less than that of the atmosphere, and expiration occurs when pressure inside the lungs is greater than that of the atmosphere.

The **diaphragm**, a dome-shaped sheet of muscle that separates the thoracic, or chest, cavity from the abdominal cavity, can regulate the pressure in the chest cavity. During inspiration, the diaphragm muscle contracts, or shortens, pulling downward. The chest volume increases and pressure in the lungs decreases. The atmospheric pressure is now greater than the pressure in the chest cavity, and air moves into the lungs. During expiration, the diaphragm relaxes and returns to its dome shape due to the force exerted by the organs in the abdomen. The chest volume decreases and pressure increases. The pressure in the chest cavity is now greater than the atmospheric pressure, and air moves out of the lungs.

DID YOU KNOW?

Chest Wound First-Aid

If you are injured and have a hole in your chest, one first-aid technique is to place your hand over the wound to create a seal.

diaphragm a sheet of muscle that separates the organs of the thoracic cavity from those of the abdominal cavity

The diaphragm is assisted through the action of the intercostal muscles, which cause the ribs to move (**Figure 5**). Have you ever noticed how your ribs rise when you inhale? The ribs are hinged to the vertebral column, allowing them to move up and down. Bands of muscle, the **intercostal muscles**, are found between the ribs. A nerve stimulus causes the intercostal muscles to contract, pulling the ribs upward and outward. This increases the volume of the chest, lowers the pressure in the chest cavity, and air moves into the lungs. If the intercostals are not stimulated, the muscles relax and the rib cage falls. The chest wall pushes against the lungs with greater pressure, and air is forced out of the lungs.

intercostal muscle a muscle that raises and lowers the rib cage

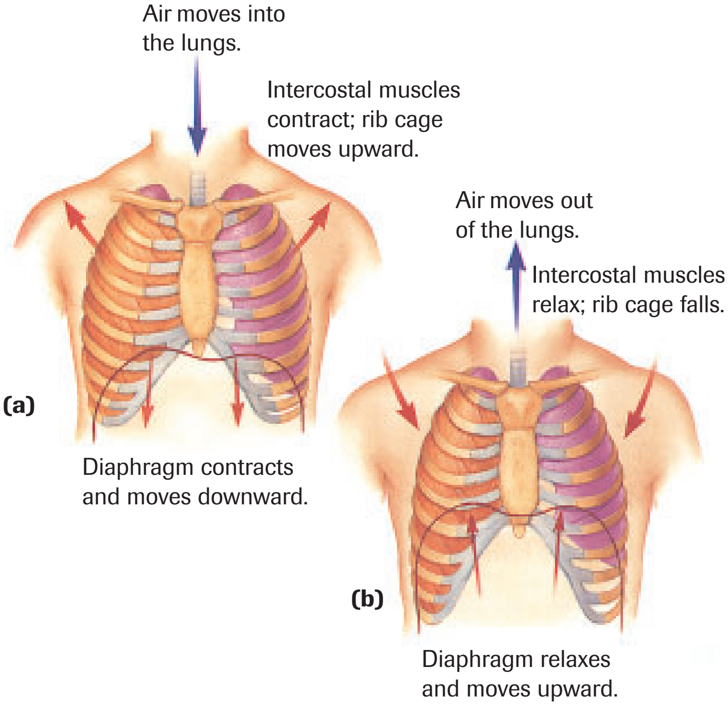

Figure 5
Changes in chest volume during inspiration and expiration
(a) The intercostal muscles contract and the rib cage pulls upward. Because pressure in the chest cavity is lower than the atmospheric pressure, air moves into the lungs.
(b) The intercostal muscles relax and the rib cage falls. Because pressure in the chest cavity is higher than the atmospheric pressure, air moves out of the lungs.

The importance of the pressure difference between the lungs and the atmosphere can be illustrated by a pneumothorax. A pneumothorax is an accumulation of air inside the chest in the space between the pleural membranes that line the lungs and the inner chest wall. The pressure of the air causes the lung to collapse. A traumatic pneumothorax results from a penetrating injury to the chest, such as a bullet hole or stab wound. When the diaphragm contracts and the rib cage rises, the pressure inside the chest cavity is reduced; however, air flows directly through the hole in the chest. To treat a pneumothorax, the air must be removed so that the lung can re-expand.

EXTENSION

Pressure-gradient Changes During Respiration
This animation discusses ventilation and examines the relationship between atmospheric and intra-alveolar pressure.

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INVESTIGATION 9.1 *Introduction*

Determining Lung Capacity

The lungs of healthy, fit people tend to have a greater volume than the lungs of those who experience poor health or who are less fit. What is your lung capacity?

Report Checklist

- ● Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

To perform this investigation, turn to page 305.

SUMMARY The Importance of an Oxygen Delivery System

- The cells of the body obtain energy through oxidation. Thus, oxygen is essential to survival.
- Respiration includes all the processes involved in the exchange of oxygen and carbon dioxide between cells and the environment.
- Air enters the respiratory system through the nose or the mouth; then, it enters the pharynx, trachea, bronchi, and the bronchioles and alveoli in the lungs.
- In the alveoli, gases diffuse between air and blood according to concentration gradients. Oxygen moves into the alveoli and carbon dioxide moves out of the alveoli.
- The movement of gases into and out of the lungs is determined by the difference in pressure between the atmosphere and the thoracic cavity. Pressure in the thoracic cavity is regulated by the diaphragm. The diaphragm is assisted by the movement of the intercostal muscles.
  - During inspiration (inhalation), the intercostal muscles contract, the diaphragm flattens and pulls downward, the rib cage pulls up and outward, chest volume increases, pressure in the lungs decreases, and air moves into the lungs.
  - During expiration (exhalation), the intercostal muscles relax, the diaphragm becomes dome shaped, the rib cage falls, chest volume decreases, pressure in the lungs increases, and air moves out of the lungs.

Section 9.1 Questions

1. Describe the similarities and differences between the bronchi, bronchioles, and alveoli. How is each type of structure well suited for its purpose in the lungs?
2. Explain how and why oxygen and carbon dioxide diffuse between the alveoli and the air in the lungs.
3. Why does a throat infection cause your voice to produce lower-pitched sounds?
4. Trace the pathway of a breath of air from its point of entry to its diffusion in the lungs. Refer to the structures that the air passes by or through.
5. What is respiratory distress syndrome?
6. Why does the buildup of fluid in the chest cavity, as occurs with pleurisy, make exhalation easier but inhalation more difficult?
7. Describe the movements of the ribs and the diaphragm during inhalation and exhalation.
8. Bronchitis is an inflammation of the bronchi or bronchioles that causes them to swell. What problems would be caused as the airways swell and decrease in diameter?
9. Nicotine inhaled with cigarette smoke causes blood vessels to narrow. What problems would this cause for the cells of the body?

9.2 Gas Exchange and Transport

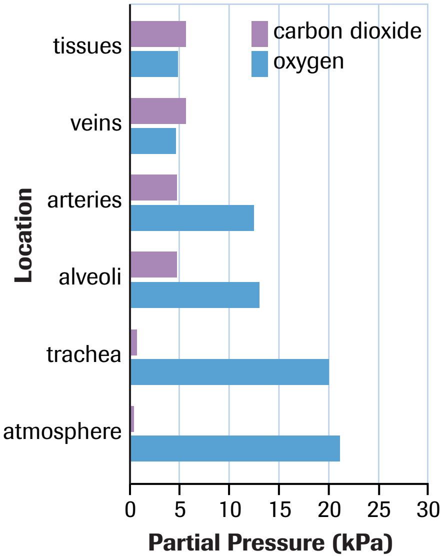

Figure 1
Partial pressures of oxygen and carbon dioxide

An understanding of gas exchange in the human body is tied to an understanding of the physical nature of gases. As mentioned in the previous section, gases diffuse from an area of higher pressure to an area of lower pressure.

Dalton's law of partial pressure states that each gas in a mixture exerts its own pressure, or partial pressure. The graph in **Figure 1** shows the partial pressures of oxygen and carbon dioxide in the body. Gases diffuse from an area of high partial pressure to an area of lower partial pressure. The highest partial pressure of oxygen is found in atmospheric air. Oxygen diffuses from the air (21.2 kPa) into the lungs (13.3 kPa for the alveoli).

The partial pressure of oxygen in the blood differs depending on location. Arteries carry blood away from the heart while veins carry it back to the heart. Arteries are connected to veins by capillaries, where gas exchange takes place and oxygen diffuses into the tissues. (Remember that energy is continuously released from nutrients by reactions within the cells that require oxygen. Oxygen will never accumulate in the cells.) Therefore, the largest change in the partial pressure of oxygen is observed as oxygen travels from the arteries (12.6 kPa) into the capillaries (5.3 kPa).

Carbon dioxide, the product of cellular respiration, follows an opposite pattern. Partial pressure of carbon dioxide is highest in the tissues and venous blood. The partial pressure of nitrogen, although not shown in the graph, remains relatively constant. Atmospheric nitrogen is not involved in cellular respiration.

Practice

1. (a) Where is the partial pressure of oxygen the highest? the lowest?
   (b) How is this related to the diffusion of oxygen into the tissues?
2. Where is the partial pressure of carbon dioxide the highest? the lowest?

Oxygen Transport

Oxygen (O_2) moves from the atmosphere, the area of highest partial pressure, to the alveoli. It then diffuses from the alveoli into the blood and dissolves in the plasma. Oxygen is not very soluble in blood—about 0.3 mL of oxygen per 100 mL of blood. However, even at rest, the body requires approximately 10 times that amount of oxygen. **Hemoglobin** greatly increases the oxygen-carrying capacity of the blood. The hemoglobin molecule consists of four polypeptides that are composed of heme, the iron-containing pigment, and globin, the protein component. Each heme group contains an iron atom, which binds with oxygen. When oxygen dissolves into the plasma, hemoglobin forms a weak bond with the oxygen molecule to form **oxyhemoglobin**. Once oxyhemoglobin is formed, other oxygen molecules can dissolve in the plasma. With hemoglobin, the blood can carry 20 mL of oxygen per 100 mL of blood, almost a 70-fold increase.

The amount of oxygen that combines with hemoglobin is dependent on partial pressure. The partial pressure in the lungs is approximately 13.3 kPa. Thus, blood leaving the lungs is still nearly saturated with oxygen. As blood enters the capillaries, the partial pressure drops to about 5.3 kPa. This drop in partial pressure causes the dissociation, or split, of oxygen from the hemoglobin, and oxygen diffuses into the tissues. **Figure 2** (on the next page) shows an oxygen–hemoglobin dissociation curve. You will notice that very little oxygen is released from the hemoglobin until the partial pressure of oxygen reaches 5.3 kPa. This ensures that most of the oxygen remains bound to the hemoglobin

hemoglobin the oxygen-carrying molecule in red blood cells

oxyhemoglobin hemoglobin that is bound to oxygen

EXTENSION

Partial Pressure Gradients
Oxygen and carbon dioxide exchange occurs across capillaries and is driven by partial pressure gradients. This animation reviews the partial pressures of CO_2 and O_2 in different regions of the body.

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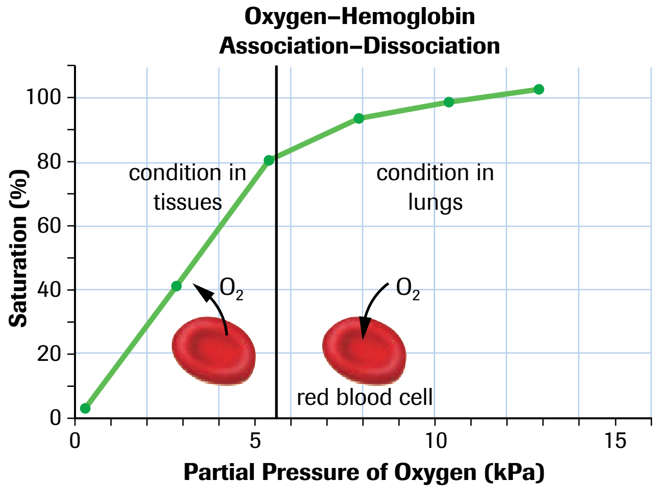

Figure 2
Oxygen–hemoglobin dissociation curve

until it gets to the tissue capillaries. Also note that venous blood still carries a rich supply of oxygen. Approximately 70 % of the hemoglobin is still saturated when blood returns to the heart.

EXTENSION

The Oxyhemoglobin Dissociation Curve
This Audio Clip analyzes the oxyhemoglobin dissociation curve and its correlation to hemoglobin's changing affinity for oxygen, as it gains and loses oxygen molecules.

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Carbon Dioxide Transport

Carbon dioxide (CO_2) is about 20 times more soluble than oxygen. About 9 % of the carbon dioxide produced by the tissues of the body is carried in the plasma. Approximately 27 % of the body's carbon dioxide combines with hemoglobin to form carbaminohemoglobin. The remaining 64 % of the body's carbon dioxide combines with water from the plasma to form carbonic acid (H_2CO_3):

$$CO_2 + H_2O \rightarrow H_2CO_3$$

An enzyme called **carbonic anhydrase** increases the rate of this chemical reaction by about 250 times. The rapid conversion of free carbon dioxide into carbonic acid decreases the concentration of carbon dioxide in the plasma. This maintains a low partial pressure of carbon dioxide, ensuring that carbon dioxide continues to diffuse into the blood (**Figure 3**).

carbonic anhydrase an enzyme found in red blood cells that speeds the conversion of carbon dioxide and water to carbonic acid

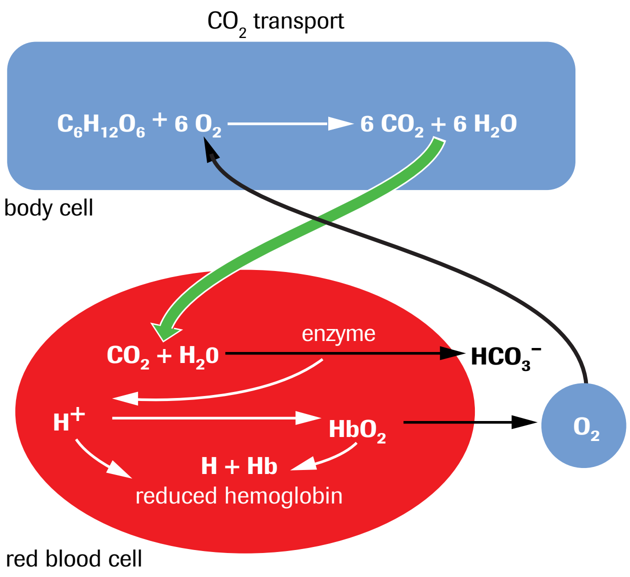

Figure 3
Under the influence of carbonic anhydrase, an enzyme found in red blood cells, carbon dioxide combines with water to form carbonic acid (H_2CO_3), which then, dissociates into H^+ and HCO_3^- ions.

CHEMISTRY CONNECTION

Acids and Bases

When carbon dioxide dissolves in the water in plasma, it forms carbonic acid. You can learn more about acids and bases in your chemistry course.

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The formation of acids, such as carbonic acid, can create problems. Because acids can change the pH of the blood and eventually bring about death, they must be buffered. This is where the second function of hemoglobin comes into effect. Being unstable, the carbonic acid dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+):

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

The hydrogen ions help dislodge oxygen from the hemoglobin, and then combine with the hemoglobin to form reduced hemoglobin. When hemoglobin combines with the hydrogen ions, it is removing H^+ from the solution; that is, the hemoglobin is acting as a **buffer**. Meanwhile, the bicarbonate ions are transported into the plasma. Oxygen is released from its binding site and is now free to move into the body cells.

buffer a substance capable of neutralizing acids and bases, thus maintaining the original pH of the solution

Once the venous blood reaches the lungs, oxygen dislodges the hydrogen ions from the hemoglobin binding sites. Free hydrogen and bicarbonate ions combine to form carbon dioxide and water:

$$H^+ + HCO_3^- \rightarrow H_2O + CO_2$$

The highly concentrated carbon dioxide diffuses from the blood into the alveoli and is eventually eliminated during exhalation.

DID YOU KNOW?

Andean Aboriginals

There is less air at high altitudes, than at sea level, so a person inhales fewer oxygen molecules with each breath. Andean highlanders, the Quechua and Aymara, have adapted to living high in the mountains. Their red blood cells contain more hemoglobin than people living at sea level. Although both groups breathe at the same rate, the Andean highlanders deliver oxygen to their cells more efficiently.

Maintaining Gas Levels

A variety of mechanisms exist to help maintain appropriate levels of oxygen and carbon dioxide. For example, a chemical receptor helps ensure that carbon dioxide, the waste product of cellular respiration, does not accumulate. During exercise, cellular respiration increases, causing carbon dioxide levels to increase. This stimulates chemical receptors in the brainstem. The activated nerve cells from the brain carry impulses to muscles that increase breathing movements. Increased breathing movements help flush excess carbon dioxide from the body. Other chemical receptors in the walls of the carotid artery are able to detect low levels of oxygen in the blood. A nerve is stimulated and a message is sent to the brain. The brain relays the information, by way of another nerve, to the muscles that control breathing. Thus, a system of "turning on" and "turning off" mechanisms is used to help maintain equilibrium.

EXPLORE an issue

Issue Checklist

○ Issue ○ Design ● Analysis
● Resolution ● Evidence ● Evaluation

Using Erythropoietin to Increase Oxygen-Carrying Capacity

In the past, drug use in sports was most often linked to power sports such as weightlifting and sprinting. Steroids increase muscle mass and strength.

In the late 1980s, endurance athletes turned to erythropoietin (EPO), a naturally occurring hormone that promotes the production of red blood cells in the bone marrow. By increasing red blood cell production, the oxygen-carrying capacity of the blood is improved and more oxygen can be delivered to the tissues. You know the saying about "too much of a good thing"? In the case of EPO, the problem is too many red blood cells in the blood. Although oxygen delivery is improved, the blood becomes thicker and more difficult to move through the blood vessels. This, in turn, can cause an increased incidence of stroke, heart attack, and heart failure. In 1988, EPO was linked to the death of at least 20 cyclists.

Despite the adverse effects, athletes continue to use EPO for many different sports, and deaths associated with the hormone continue. In the 2002 Olympic Games, Canadian cross-country skier Beckie Scott (**Figure 4**, next page) had her bronze medal elevated to gold when both the gold and silver medallists in the event tested positive for EPO.

Figure 4
Beckie Scott's bronze medal was elevated to a gold medal in cross-country skiing because the two other winning athletes had used performance-enhancing drugs.

Statement
Although individual athletes are banned for drug use in Olympic sports, it continues to be a problem. The ban should be extended to all athletes from that country in that particular sport for a defined number of years.

1. Form a group and research the issue.

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2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statement. Should an entire country be banned from a sport for the actions of one individual?
5. Defend your position in the debate.

SUMMARY *Gas Exchange and Transport*

- Gases diffuse from an area of higher pressure to an area of lower pressure.
- The partial pressure of oxygen is highest in the atmosphere and lowest in the veins and tissues.
  – Oxygen diffuses from the atmosphere into alveoli and then, into the blood.
  – Hemoglobin bonds to oxygen molecules to form oxyhemoglobin. Hemoglobin and oxygen dissociate in the capillaries, and oxygen diffuses into the tissues.
- The partial pressure of carbon dioxide is highest in the tissues and veins and lowest in the atmosphere.
  – Some carbon dioxide combines with water from plasma to form carbonic acid; this decreases the carbon dioxide concentration in the blood, ensuring that carbon dioxide continues to diffuse into the blood.
  – Carbonic acid dissociates into HCO_3^- and H^+. Hemoglobin combines with H^+, releasing oxygen and acting as a buffer.
  – In the lungs, H^+ and HCO_3^- combine to form carbon dioxide and water. Carbon dioxide is highly concentrated; it diffuses from the blood into alveoli and is eliminated through exhalation.
- To help maintain equilibrium, chemical receptors detect a change in gas levels and send a message to increase or decrease breathing rate.

CAREER CONNECTION

Commercial Diver
Commercial divers need to know about the partial pressure of gases. These divers work in constructing or inspecting underwater machinery, including offshore oil and gas rigs. Breathing atmospheric concentrations of oxygen can cause problems when commercial divers do deep dives. Learn how someone would become a commercial diver, and explore the types of work done.

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Section 9.2 Questions

1. How does partial pressure affect the movement of oxygen from the alveoli to the blood?
2. How is carbon dioxide transported in the blood?
3. Describe the importance of hemoglobin as a buffer.
4. Trace the pathway of an oxygen molecule from the atmosphere to its combination with a hemoglobin molecule.
5. What is the function of carbonic anhydrase?

9.3 Regulation of Breathing Movements

Breathing movements are controlled by nerves from the medulla oblongata in the brain (**Figure 1**). Information about the accumulation of carbon dioxide (CO_2) and acids and the need for oxygen is detected by **chemoreceptors**. Two different types of receptors are oxygen chemoreceptors and carbon dioxide, or acid, chemoreceptors. The carbon dioxide receptors are the most sensitive and are the main regulators of breathing movements.

chemoreceptor a specialized nerve receptor that is sensitive to specific chemicals

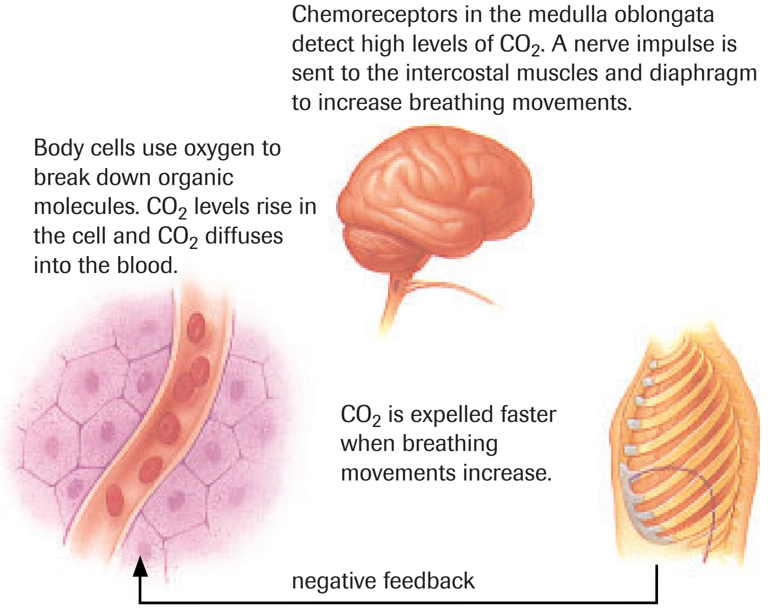

Figure 1
Carbon dioxide control

CO_2 dissolves in the blood and forms an acid. Should the CO_2 accumulate, special chemoreceptors in the medulla oblongata become activated. Once activated, the medulla oblongata relays messages to the intercostal muscles and diaphragm to increase breathing movements. The acceleration of the breathing rate decreases the levels of CO_2 in the blood. Once CO_2 levels fall, the chemoreceptors become inactive, and the breathing rate returns to normal.

A second monitoring system, which relies on chemoreceptors sensitive to oxygen, is found in the carotid and aortic arteries (**Figure 2**). Referred to as the *carotid* and *aortic bodies*, these specialized receptors are primarily responsible for detecting low levels of oxygen. When stimulated, the oxygen receptors send a nerve impulse to the medulla oblongata. Once activated, the medulla sends nerve impulses to the intercostal muscles and diaphragm to increase breathing movements. Increased ventilation increases blood oxygen, thereby, compensating for low levels of oxygen. A secondary function of these bodies is to detect high blood CO_2 or high levels of acidity, although the medulla oblongata is the more sensitive receptor of CO_2.

Because the CO_2 receptors are more sensitive to changes in blood chemistry, the oxygen receptors act as a backup system. The oxygen receptors are only called into action when oxygen levels fall and CO_2 levels remain within the normal range. For example, when you hold your breath, CO_2 levels rise and oxygen levels drop—the high CO_2 levels would initiate increased breathing movements. However, the situation differs at high altitudes, where the air is thinner and fewer oxygen molecules are found. Since low oxygen levels are not accompanied by higher CO_2 levels, the

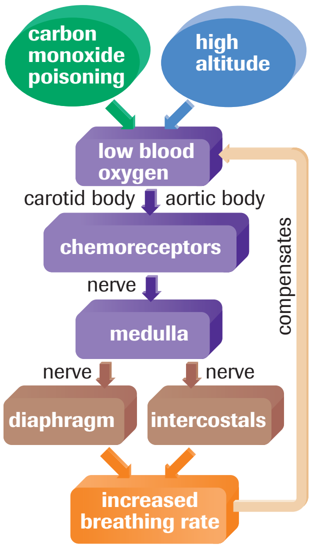

Figure 2
Low blood oxygen levels are detected by special oxygen chemoreceptors in the aorta and carotid arteries.

chemoreceptors in the carotid and aortic bodies stimulate breathing movements. Increased ventilation helps establish normal blood oxygen levels.

Response of the Respiratory System to Exercise

The ventilation of the alveoli can increase up to 20 times with heavy exercise to keep up with the demands for increased oxygenation and the need to expel CO_2. Although all the factors that cause increased ventilation of the lungs are not known, three factors play an important role: decreased O_2, increased CO_2, and increased H^+. **Figure 3** outlines some of the body's responses to exercise.

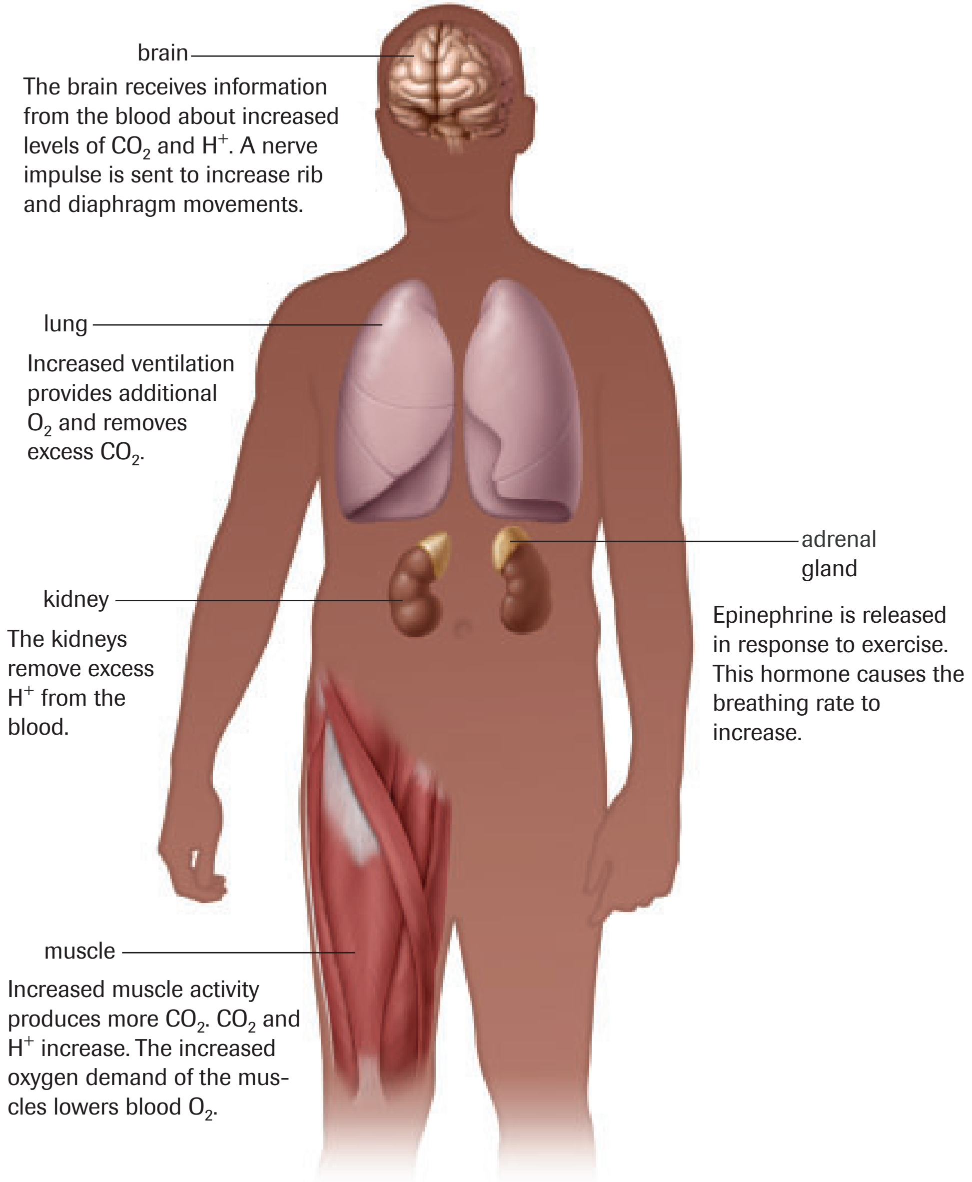

Figure 3
The body's response to exercise

DID YOU KNOW?

Carbon Monoxide Poisoning

Carbon monoxide (CO) poisoning is another example of how falling blood oxygen levels stimulate increased breathing rate. Carbon monoxide competes with oxygen for the active site on the hemoglobin molecule. Unfortunately, CO gains faster access. As more hemoglobin molecules bind with CO, less oxygen is carried to the tissues. The carbon dioxide level tends not to increase. Eventually, the low oxygen level is detected by the chemoreceptors and breathing movements increase.

INVESTIGATION 9.2 *Introduction*

The Effects of Exercise on Lung Volume

Different factors can affect the volume of a single breath. In this investigation, you will design and carry out an experiment on how exercise affects lung volume.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

To perform this investigation, turn to page 306.

Figure 4
Dr. Malcolm King

WEB *Activity*

Canadian Achiever—Dr. Malcolm King

Dr. Malcolm King (**Figure 4**), a Professor in the Department of Medicine at the University of Alberta, began his career as a chemist, studying polymers. He now applies this knowledge to studies of the role of mucus from the lungs in two serious disorders of the respiratory system, cystic fibrosis and chronic obstructive lung disease. Dr. King is a leader in his field, having published over 160 papers, and is the recipient of many awards. A member of the Mississaugas of the New Credit First Nation in Southern Ontario, Dr. King is also interested in training Aboriginal students in medicine, and in examining traditional medicines used to treat respiratory diseases. Conduct additional research on Dr. Malcolm King, his research, and his leadership role in science and Aboriginal issues.

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bronchitis an inflammation of the bronchial tubes

emphysema a respiratory disorder characterized by an overinflation of the alveoli

EXTENSION

CBC radio ONE
QUIRKS & QUARKS

Pillow Fungus
Professor Ashley Woodcock describes her discovery of an entire ecosystem that exists in our pillows. This ecosystem includes multiple species of potentially allergenic fungus, bacteria and dust mites. While this is definitely a problem for individuals with respiratory ailments such as asthma and allergies, research continues to see if it is problem for others without any previous allergies.

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Disorders of the Respiratory System

All respiratory disorders share one common characteristic: they all decrease oxygen delivery to the tissues.

Bronchitis

Bacterial or viral infections, as well as reactions to environmental chemicals, can cause a variety of respiratory problems. **Bronchitis** is an ailment characterized by narrowing of the air passages and inflammation of the mucous lining in the bronchial tubes. This leads to excess production of mucus, tissue swelling, a narrowing of the air passages, and decreased air movement through the bronchi. The condition becomes even more serious in the bronchioles. Unlike the trachea and the bronchi, the bronchioles are not supported by bands of cartilage to help keep them open.

Emphysema

In **emphysema**, the walls of the alveoli become inflamed. Over time, this destroys the air sacs, causing them to lose their elasticity, stretch, and eventually rupture. As a result, it becomes difficult to exhale and air becomes trapped in the lungs. The fact that there are fewer alveoli means there is less surface area for gas exchange which, in turn, leads to decreased oxygen levels. The most common cause of emphysema is smoking. Emphysema is associated with chronic bronchitis. Together they are known as chronic obstructive pulmonary disease (COPD). Like bronchitis, COPD involves an increased resistance to airflow through the bronchioles. Although air flows into the alveoli fairly easily, the decreased diameter of the bronchioles creates resistance to the movement of air out of the lungs and exhalation becomes laboured. In the body's attempt to maintain equilibrium, the breathing rate increases. The circulatory system adjusts by increasing the heart rate.

Practice

1. What is bronchitis? What are its effects on the respiratory system?
2. Describe the pressure changes that occur in the lungs during breathing for someone with emphysema.

WEB Activity

Simulation—Asthma

Bronchial asthma is associated with the inflammation of the bronchioles. In asthma, greater effort is required to exhale than to inhale. The imbalance between the amount of air entering the lungs and the amount of air leaving the lungs must be met by increasing the exertion of expiration. In this activity, you will view the events that occur in the lung during an asthma attack. Why does the imbalance in the amount of air entering and leaving the lungs occur?

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bronchial asthma a respiratory disorder characterized by reversible narrowing of the bronchial passages

Case Study

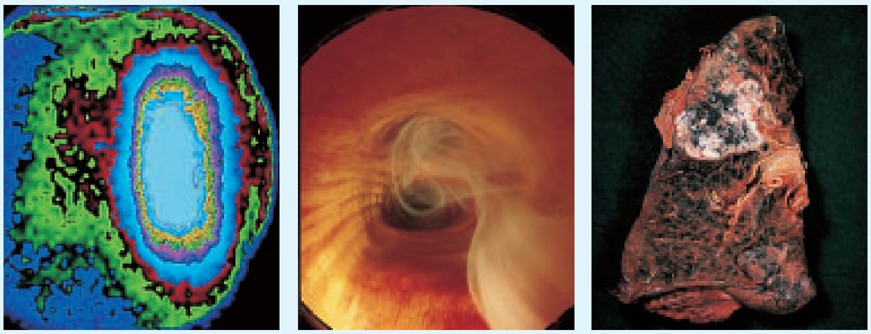
Smoking and Lung Cancer

More Canadian men and women die from lung cancer than from any other form of the disease (**Figure 5**). As in other cancers, there is uncontrolled growth of cells. The solid mass of cancer cells in the lungs greatly decreases the surface area for diffusion. Tumours may actually block bronchioles, thereby reducing airflow to the lungs and potentially causing the lung to collapse.

In contrast to skin cancers, lung cancers are almost always fatal—the five-year survival rate is not much better than 15 %. Lung cancer is the second most common cancer, yet it is one of the most preventable. Prior to the use of tobacco, lung cancer was relatively rare. Smoking increased in popularity in the 1920s and it was usually men who smoked. In the 1940s, lung cancer began to increase at a dramatic rate, becoming the most common cancer in men. As more and more women began to smoke, lung cancer cases among women also rose significantly. In 1995, lung cancer surpassed breast cancer as the number one cancer killer of women. The World Health Organization estimates that, every year, 4 million people die as a result of smoking tobacco. This figure is expected to rise to 10 million by 2010.

When smokers quit, their risk of developing lung cancer lessens over time (**Figure 6**, next page). Also, as with most cancers, if lung cancer is detected at an early stage, there is a greater chance of survival. Some common symptoms include an unusual cough, sputum containing blood, hoarseness, and shortness of breath which is noticeable during physical activity. **Figure 7**, on the next page, shows how the bronchioles and alveoli of a smoker appear in comparison to those of a nonsmoker.

How does smoking lead to lung cancer? Cancer usually begins in the bronchi or bronchioles. Components of cigarette smoke contribute to the development of cancerous tumours. The four diagrams in **Figure 8**, on the next page, show the development and progression of lung cancer. Cigarette smoke travels through the bronchioles and irritates the cells. Special



(a) (b) (c)

Figure 5
(a) A lung scan reveals cancer of the lung. The colours in the healthy lung indicate normal ventilation. On the left side, the absence of the normal colours and the presence of the purple colour indicate a nonfunctioning lung.
(b) Smoke descends toward the lungs.
(c) Postmortem specimen of a human lung shows a cancerous tumour of the upper lobe as a black and white area. The entire lung is permeated with black, tarry deposits, suggesting a history of heavy smoking.

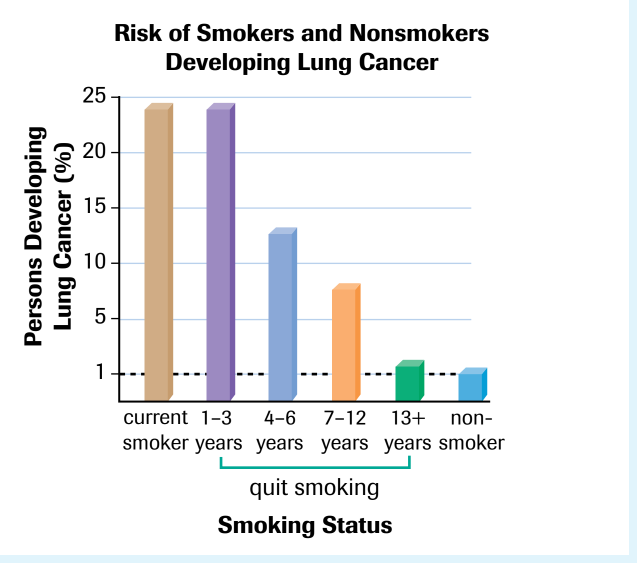


Figure 6
When smokers stop smoking, their risk of lung cancer decreases with time.

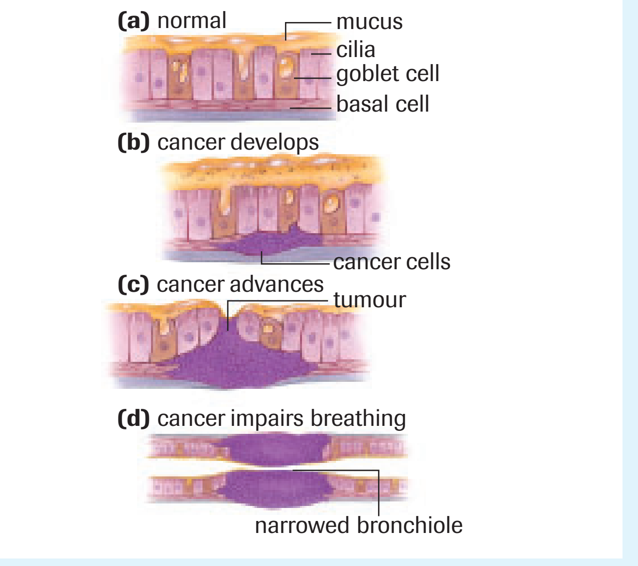


Figure 8
Development of a tumour in the tissues of the bronchiole walls

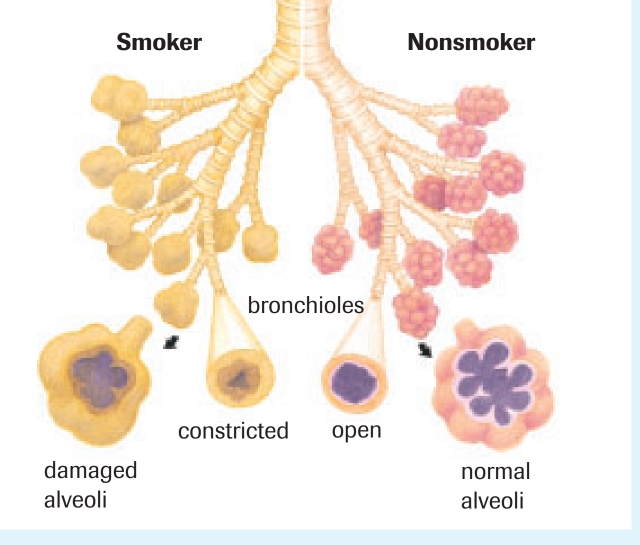


Figure 7
A comparison of the bronchioles and alveoli of a smoker and a nonsmoker

cells produce mucus, which is designed to trap foreign particles. Compare the mucous layers in **Figures 8 (a)** and **(c)**. Ciliated cells line the bronchioles. Cilia sweep away the debris trapped by the mucus. Unfortunately, the tar found in cigarette smoke slows the action of the cilia. The sludgelike tar becomes trapped in the mucus. **Figure 8 (b)** shows the beginning of a cancerous tumour and **Figure 8 (c)** shows how the tumour advances. Note the location of the tumour and its growth. While the tumour is still walled in by the basal membrane in **Figure 8 (c)**, it has broken through the membrane in **Figure 8 (d)**.

Case Study Questions

1. How does cigarette smoke affect the mucous layer in the bronchioles?
2. Why does the buildup of tar in the bronchioles limit airflow?
3. In what area does a tumour begin to develop?
4. Why has the mucous layer in **Figure 8 (c)** decreased in size?
5. Cancer cells often travel in lymph vessels to other parts of the body, where they continue to divide. Why does this characteristic make cancer especially dangerous?
6. At what stage might cells break away and cause a tumour in another area of the body?
7. The Canadian tobacco industry employs thousands of full-time and part-time workers. Thousands of seasonal workers are also employed, and thousands of wholesale and retail workers profit from the sale of tobacco products. The government also raises money through tobacco taxation, and the tobacco industry's contributions to the Canadian economy are large. However, the costs associated with smoking are also large. Do you think that the government should ban the sale of tobacco products? Defend your position.

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WEB Activity

Web Quest—Smokeless Tobacco

Most people agree that smoking is bad for your health. This Web Quest takes a look at an alternative to smoking—smokeless tobacco! What are the issues surrounding the use of this drug? Is it really an acceptable alternative or is it just as unhealthy? Explore this issue and compose a letter outlining whether you agree or disagree with using federal money to support research on smokeless tobacco.

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SUMMARY Regulation of Breathing Movements

- Breathing movements are regulated by the medulla and by chemoreceptors in the carotid artery and the aorta.
- All respiratory disorders decrease oxygen delivery to the tissues. Healthy lungs are much more efficient at gas exchange than unhealthy lungs are.
- Bronchitis is an inflammation of the bronchioles, which results in narrowed air passages and decreased air movement.
- Emphysema is inflammation and overinflation of the alveoli, causing them to rupture and reducing the surface area available for diffusion.
- Bronchial asthma is characterized by narrowing of the bronchial passages.
- Lung tumours reduce the surface area for diffusion.

EXTENSION

Search for a Safe Cigarette

The tobacco industry's quest for a "safer" cigarette is filled with promise and pitfalls, as presented in this *NOVA* video.

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Section 9.3 Questions

1. How do CO_2 levels regulate breathing movements?
2. Why does exposure to carbon monoxide (CO) increase breathing rates?
3. How does emphysema affect the lungs?
4. How does partial pressure affect the movement of oxygen from the alveoli to the blood?
5. How is CO_2 transported in the blood?
6. Why is the slowing down of the cilia in smokers dangerous?
7. Nicotine, one of the components of cigarettes, slows the cilia lining the respiratory tract, causes blood vessels to constrict, and increases heart rate. Another component of cigarette smoke is carbon monoxide. Carbon monoxide competes with oxygen for binding sites on the hemoglobin molecule found in red blood cells. Analyze the data presented in this chapter, and describe the potential dangers associated with smoking.
8. Survey several people who smoke and calculate the amount of tar taken in each day. Most cigarettes contain about 15 mg of tar, with 75 % of the tar being absorbed. Show your calculations.
9. On an X ray, a cancerous tumour shows up as a white spot (**Figure 9**). A healthy lung appears dark. Why would the tumour appear white?

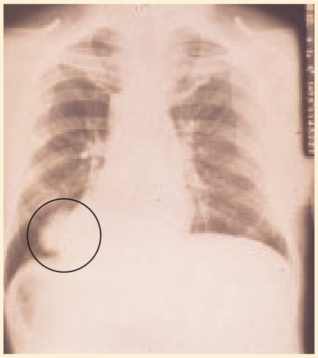

Figure 9
An X ray showing the presence of a tumour in the lower right lung

9.4 Muscles

cardiac muscle the involuntary muscle of the heart

smooth muscle the involuntary muscle found in the lining of many organs

skeletal muscle the voluntary muscle that makes the bones of the skeleton move

tendon a band of connective tissue that joins muscle to bone

antagonistic muscles a pair of skeletal muscles that are arranged in pairs and that work against each other to make a joint move

Your body has more than 600 muscles that can be divided into three basic types (**Figure 1**). **Cardiac muscle** is the muscle that makes the heart beat, and it is found only in the heart. Cardiac muscle contracts and relaxes automatically (involuntarily) because it is controlled by nerves of the autonomic nervous system. **Smooth muscle** is found in the lining of organs such as the stomach, the esophagus, the uterus, and the walls of blood vessels. Smooth muscle contractions move food through the digestive system and help push a baby through the vagina during delivery. Smooth muscle contraction is also involuntary. Unlike cardiac muscle and smooth muscle, the muscles that are attached to the bones of the skeleton are under conscious (voluntary) control, and are called **skeletal muscle**. **Figure 2**, on the next page, shows some of the main skeletal muscles of the body. These are the muscles that allow you to walk, talk, and hit a baseball with a bat. Skeletal muscles are attached to bones by **tendons**.

Muscles shorten when they contract and lengthen when they relax. A body part moves only when a contracting muscle pulls it. Many skeletal muscles are arranged in pairs that work against each other to make a joint move. These are called **antagonistic muscles**. The biceps and triceps muscles of the arm are an antagonistic pair of muscles (**Figure 3**, next page). When the biceps contracts and the triceps relaxes, the bones forming the elbow joint are brought closer together. When the biceps relaxes and the triceps contracts, the two bones are moved apart. The muscle that must contract to bend a joint is

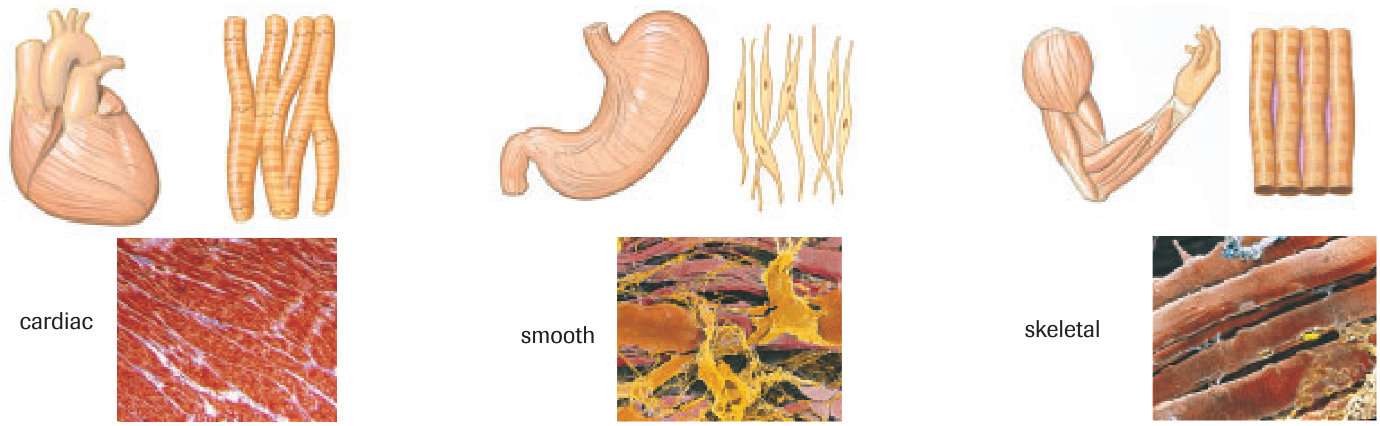

Figure 1
Types of muscle

mini Investigation — Microscopic Examination of Muscle

In this activity, you will examine and compare the structures of cardiac, smooth, and skeletal muscle.

Materials: prepared slides of cardiac, smooth, and skeletal muscle

- Examine the three types of muscle under low, medium, and high power magnification.

(a) Draw a diagram of each muscle type under low power magnification. Label the nuclei, cell membranes, and striation if visible.

(b) In a chart, describe the similarities and differences that you observed among the muscle types.

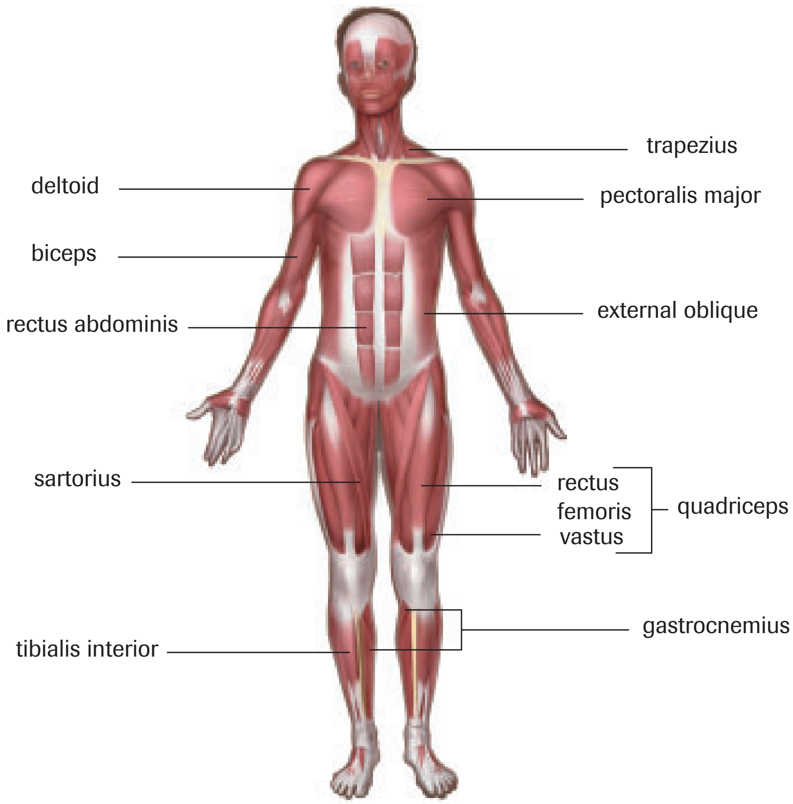

Figure 2
Some major muscles of the human body

DID YOU KNOW?

The Triceps

Have you ever admired a bulging biceps? Although bodybuilders work hard to develop well-defined biceps muscles, it is the triceps that are used most often during sports that require throwing, such as baseball, javelin, and shot put.

called a **flexor**, so the biceps muscle is a flexor. The muscle that must contract to straighten a joint is called an **extensor**. The triceps muscle is an extensor muscle. The origin is the place where the muscle attaches to the stationary bone; the insertion is where it attaches to the moving bone.

The central nervous system ensures that the biceps and triceps do not attempt to pull against each other. Excitatory nerve impulses that cause the triceps to contract are accompanied by inhibitory nerve impulses that cause the biceps to relax.

flexor the muscle that must contract to bend a joint

extensor the muscle that must contract to straighten a joint

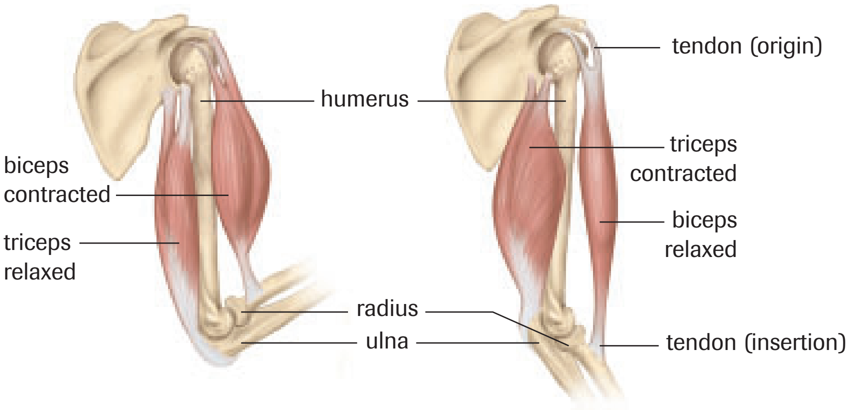

Figure 3
The biceps and triceps are an example of antagonistic muscles.

EXTENSION

The Role of the Skeleton

The skeleton is an important part of the motor system. Bones and muscles work together to permit movement. Go to the Nelson Web site to learn more about the role of the skeleton.

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mini Investigation — Effect of Low Temperature on Muscle Contraction

Materials: ice, water, large beaker, pen and paper, stopwatch

- Write your name as many times as possible in 2 min. Use a stopwatch to keep track of time. Record the number of signatures.
- Immerse your hand in ice water for as long as you can, and once again write your name as many times as possible in 2 min. Record the number of signatures.
- Rub your hand until warm and repeat the procedure.

(a) Construct a data table that compares the number of signatures to hand temperature.
(b) Compare the quality of the signatures.
(c) Why does cold water affect the muscles?

EXTENSION

General Musculo-Skeletal Anatomy
This Audio Clip describes the anatomical references that identify the interrelationships between muscles and the skeleton.

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Skeletal Muscle

Bend your elbow and squeeze your fist. The muscles in your forearm and the biceps, the large muscle above the elbow, bulge. These muscles are skeletal muscles. Skeletal muscle permits movement, enables smiling, and helps keep you warm. An estimated 80 % of the energy used in skeletal muscle contraction is lost as heat. Is it any wonder that you shiver when cold?

Skeletal muscle is composed of several bundles of cells called fibres. Unlike other cells, which contain one nucleus, many nuclei are found in each muscle cell. The fibres are enclosed within a membrane called the **sarcolemma**. Within the muscle fibres are tiny **myofilaments** bundled together (**Figure 4 (a)**). Two kinds of myofilaments can be seen under the electron microscope, each composed of a different contractile protein. Thin myofilaments are composed of actin, and thick myofilaments are composed of myosin. They overlap to produce a striated, or striped, appearance.

sarcolemma the delicate sheath that surrounds muscle fibres

myofilament a thread of contractile proteins found within muscle fibres

The alternating dark and light bands of the muscle fibres can be explained by examining the arrangement of the myofilaments. The length of the muscle fibre is defined by the Z lines that anchor the actin fibres. The area between the Z lines is the *sarcomere.* The thick myosin filaments form the darker A bands, while the thinner actin filaments allow more light to penetrate and form the lighter I bands shown in **Figure 4 (b)**.

EXTENSION

Troponin and Tropomyosin
Take a closer look at actin filaments in a skeletal muscle cell, and the two proteins which aid in muscle contraction.

www.science.nelson.com GO

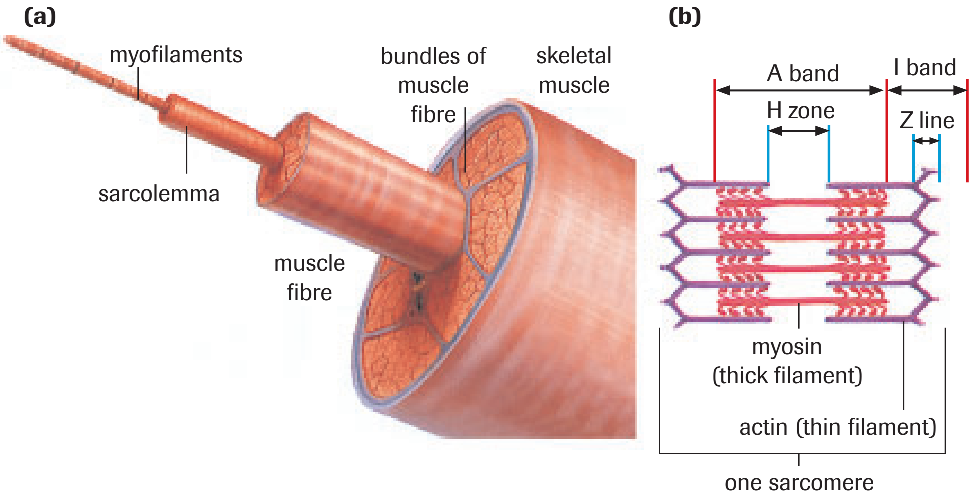

Figure 4
(a) The structure of skeletal muscle
(b) A sarcomere

The Sliding Filament Theory

As the word *theory* suggests, all is not known about muscle contraction. The sliding filament theory provides a working model that helps explain what scientists believe is happening.

Muscles cause movement by shortening. The actin filaments slide over the myosin filaments. Z lines move closer together when muscle fibres contract. As the actin and myosin filaments begin to overlap, the lighter I band becomes progressively smaller. But what causes the actin and myosin filaments to overlap? It is believed that knoblike projections on the thick myosin filaments form cross-bridges on receptor sites of the thinner actin filaments. A series of cross-bridges attach and detach as the actin filaments are drawn inward. **Figure 5** illustrates the sliding filament theory.

The energy required for muscle contraction comes from ATP, adenosine triphosphate. In the absence of ATP, the cross-bridges fail to detach and the muscle becomes rigid. A condition known as *rigor mortis* is due to the contraction of muscles following death. With death, ATP production ceases and skeletal muscle becomes fixed. The condition may last up to 60 hours after death.

The release of a transmitter chemical at the junction between the nerve and muscle initiates muscle contraction. Once the transmitter chemical reaches a specialized endoplasmic reticulum, found within the cytoplasm, calcium ions are released. The calcium ions bind to sites along the actin filaments and initiate the formation of cross-bridges with the myosin fibres. It is believed that the release of calcium ions begins the breakdown of ATP by the myosin filaments. ATP provides the energy for the filaments to slide over one another. Eventually, the calcium ions are actively taken up and stored in the specialized endoplasmic reticulum. The muscle then relaxes. When calcium ions are again released from the endoplasmic reticulum, the muscle contracts.

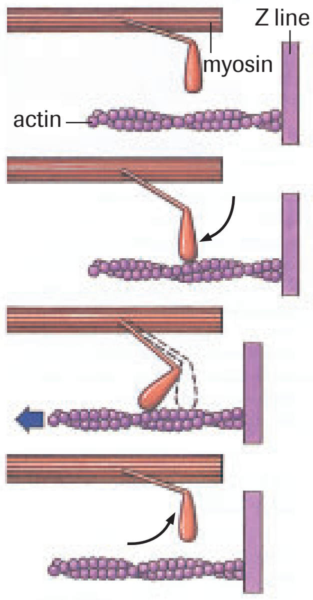

Figure 5
Sliding filament theory, showing one actin and one myosin filament

EXTENSION

Energy Sources for Contraction
In this animation, review the metabolic routes which produce ATP in muscle cells.

www.science.nelson.com GO

Muscle Fatigue

Have you ever felt your muscles begin to burn while skiing? Have your muscles ever failed you during a race? No matter how hard you try, you begin to lose control of your muscles. Muscle fatigue is caused by a lack of energy and the buildup of waste products within your muscles.

Unfortunately, very little ATP can be stored in muscle tissue. The energy demand is met by aerobic respiration. Glucose is systematically broken down by a series of enzymes found in the cytoplasm and mitochondria of your cells. Glucose is oxidized by oxygen to form ATP, carbon dioxide, and water. A high-energy compound called **creatine phosphate**, found in all muscle cells, ensures that ATP supplies remain high. Creatine phosphate supplies a phosphate to adenosine diphosphate (ADP) to replenish ATP supplies. If creatine phosphate levels remain high in muscle cells, ATP levels can be maintained.

creatine phosphate a compound in muscle cells that releases a phosphate to ADP and helps regenerate ATP supplies in muscle cells

As long as oxygen can be supplied and cellular respiration can meet the demands of muscle cells, the filaments will continue to be drawn together. However, should energy demand exceed ATP supply, lactic acid begins to accumulate. Lactic acid causes muscle pain and is associated with fatigue. The burning that you feel in your legs while skiing a difficult run or the pain the you feel in your rib muscles after prolonged heavy exercise is due to an accumulation of lactic acid. During this condition, referred to as oxygen debt, the fluids surrounding the muscles become acidic and eventually the muscle fails to contract. The rapid breathing that takes place after heavy exercise is designed to repay the oxygen debt.

CAREER CONNECTION

Prosthetist and Orthotist
Prosthetists design and construct devices such as artificial limbs, and orthotists design and construct devices such as braces and supports. They work with physicians to improve the quality of life for patients who have injuries or deformities. Find out the educational requirements for a prosthetist and orthotist.

www.science.nelson.com GO

INVESTIGATION 9.3 *Introduction*

The Effects of Muscle Activity on Body Temperature

In this investigation, you will conduct an experiment to show the relationship between muscle activity and thermal energy.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

To perform this investigation, turn to page 306.

DID YOU KNOW ?

Muscle Spasms

Muscle spasms are caused by involuntary contractions of muscles. A pinched nerve is often responsible for the spasm.

Muscle Contraction

A muscle twitch, or contraction, occurs when a nerve impulse stimulates several muscle cells. A pause between the impulse and the muscle contraction is referred to as the *latent period* (**Figure 6 (a)**). Upon contraction, actin and myosin fibres slide over one another, causing the muscle to shorten. After the contraction phase, the actin and myosin filaments disengage and the muscle begins to relax. Once the relaxation phase is complete, each muscle cell usually returns to its original length. Should a muscle cell be stimulated once again, it will contract with equal force (**Figure 6 (b)**).

An interesting phenomenon occurs when a stimulation happens before the relaxation phase is complete. Predictably, the actin and myosin filaments slide over one another, but because the relaxation has not yet been completed, the overlap is increased and greater muscle shortening can be observed. The sum of the shortening that remains from the first muscle twitch and the shortening produced by the second muscle twitch creates a greater force of contraction. The strength of the contraction depends on how close the second stimulus is to the first stimulus. The process, shown in **Figure 6 (c)**, is referred to as **summation**. Occasionally, repeated muscle stimulation prevents any relaxation phase. The state of constant muscle contraction, known as **tetanus**, is shown in **Figure 6 (d)**.

summation increased muscle contraction produced by the combination of stimuli

tetanus the state of constant muscle contraction caused by sustained nerve impulses

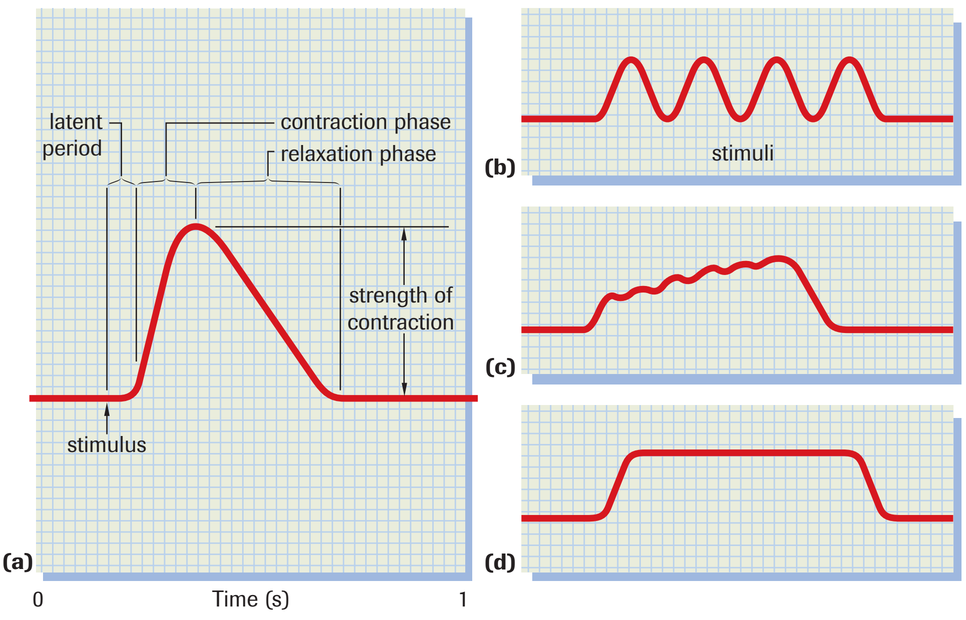

Figure 6
(a) Recording of a muscle twitch that lasts approximately 1 s
(b) Single muscle twitches approximately 1 s apart. The muscle returns to its original length before succeeding stimuli cause contractions.
(c) Summation of muscle twitches from about six stimulations every second. Following the contraction, the muscle does not have enough time to return to its original length before being stimulated again.
(d) Tetanus resulting from about 20 stimulations per second. The actin and myosin filaments remain overlapped.

Fast and Slow Twitch Muscle Fibres

It has often been said that great sprinters are born not made. Although training can improve technique, it can never make an ordinary person a world-class sprinter. The genetic factor appears too great to be overcome with increased fitness and improved technique.

Sprinters are born with a large amount of what is called fast twitch muscle fibre. It is the thick myosin filaments that determine the speed of muscle contraction. Three different forms of myosin, referred to as isomers, determine whether you have the potential to be a sprinter or a marathon runner. The fibres are referred to as type I, IIa, and IIx. Type I fibres cause slower muscle twitch and are found in greater abundance in distance runners. These fibres break down ATP slowly, but efficiently, to release energy. Type IIa and IIx fibres, the faster twitch myosin fibres, break down ATP faster, but less efficiently. The slower twitch type I fibres are required for endurance events in which aerobic metabolism is predominant. The fast twitch type IIa and IIx fibres rely predominantly on anaerobic respiration. Although all athletes have both slow and fast twitch fibres, the proportions vary dramatically, as shown in **Figure 7**.

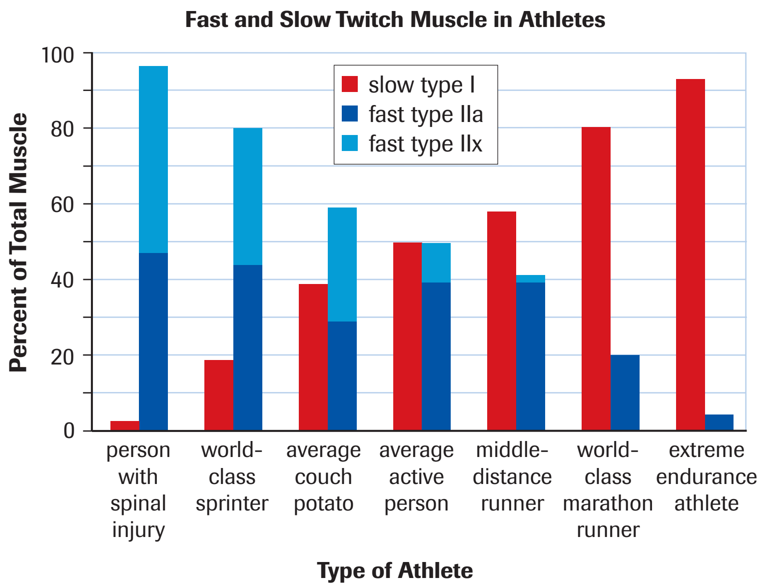

Figure 7
Different types of athletes have varying proportions of slow and fast twitch muscle fibres.

Motor System Injuries

Muscles, like all living tissues, require nourishment from a balanced diet, including an adequate supply of protein. Regular exercise is necessary for maintaining healthy muscles. Studies done in the near zero-gravity environment of outer space show that astronauts lose muscle mass unless they exercise regularly.

Motor system injuries are common in people who perform heavy work or exercise. Torn muscles, stretched tendons, torn ligaments, joint sprains, and joint dislocations are common sports injuries.

EXTENSION

Nervous System and Muscle Contraction
View this animation to see how signals from the nervous system control muscle contraction.

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DID YOU KNOW?

Red and White Muscle
There are two different types of muscle fibres. Red muscle fibres are well-suited for slow contraction, while white muscle fibres are designed for rapid contraction. Red muscle fibres appear red because they contain myoglobin, the protein that binds oxygen, which is used during cellular respiration. White fibres contain little myoglobin and, therefore, use less oxygen. They obtain energy from the breakdown of glycogen without oxygen.

EXTENSION

Comparing Fast and Slow Twitch Muscle Fibres
This Audio Clip describes the physiological differences between fast and slow twitch muscle fibres.

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Figure 8
Arthroscopic surgery

Arthroscopic Surgery

Torn cartilage or ligament? An innovative technique called arthroscopic surgery (named after the viewing device, the arthroscope) has dramatically improved the prognosis for people who suffer knee injuries.

The first arthroscope was used in Japan in 1917—today's instruments barely resemble this early predecessor. An arthroscope is a needlelike tube, less than 2 mm wide, that is equipped with a fibreoptic light source (**Figure 8**). The needle can be inserted through a small puncture in the knee, which requires only local anesthesia. The fibreoptic lens can be linked with a television screen, providing a view of the inside of the damaged knee. The arthroscope is also fitted with thin surgical tools that can snip away unhealthy tissue. Under most circumstances, hospitalization is not required following the surgery, and activity can be resumed relatively quickly.

SUMMARY *Muscles*

- The body contains three types of muscle: cardiac, smooth, and skeletal.
- The movement of bones at a joint is performed by skeletal muscles, which work in antagonistic pairs.
- Skeletal muscles are composed of muscle fibres, which contain myofilaments.
- Myofilaments are threads of contractile proteins, either actin or myosin.
- The fibres of skeletal muscle are encased in a membrane called the sarcolemma.
- The energy for muscle contraction is provided by ATP.

+ EXTENSION

Redesigning the Body for Motion

In this activity, you will re-engineer parts of the human body that are most susceptible to injuries from sports and aging.

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Section 9.4 Questions

1. What is the sarcolemma?
2. Name the two myofilaments found in muscle fibres and briefly outline their function.
3. Why does skeletal muscle appear striated, or striped?
4. Why is ATP needed for muscle contraction?
5. Why is creatine phosphate required for muscle contraction?
6. What is the term for extended muscle contraction, and what causes it?
7. Using **Figure 9**, make predictions about which athlete would be well-suited for sprinting and which for distance running. Give reasons for your prediction.

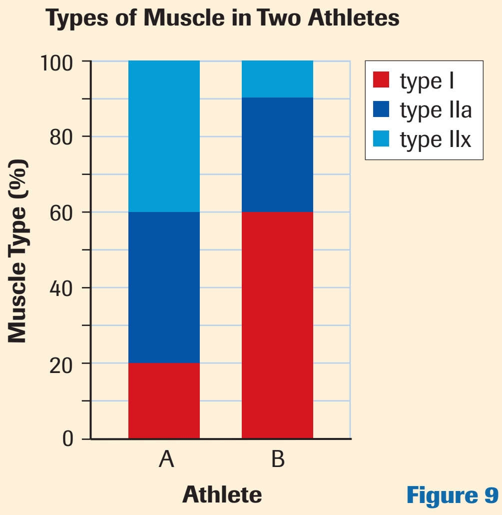

Figure 9

INVESTIGATION 9.1

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

Determining Lung Capacity

Healthy lungs can take in oxygen and expel carbon dioxide from the body with much greater efficiency than unhealthy lungs can. In this investigation, you will examine indicators of general respiratory health by measuring lung capacity at rest. Normal lung capacity (**Table 1**) varies with factors such as age, height, gender, and physical fitness.

Table 1 Approximate Lung Volumes for an Average 70-kg Male

Measure	Volume (L)
total lung capacity (TLC)	5
tidal volume (TV)	0.45 to 0.5
residual volume (RV)	1.5
expiratory reserve volume (ERV)	1.5
inspiratory reserve volume (IRV)	2.5

There are several measures that are important in determining lung capacity. The following four can be measured using a respirometer: Tidal volume (TV) is the amount of air inhaled and exhaled in a normal breath; expiratory reserve volume (ERV) is the amount of air that can be forcibly exhaled after a normal exhalation; and inspiratory reserve volume (IRV) is the amount of air that can be forcibly inhaled after a normal inhalation. Vital capacity (VC) is the maximum amount of air that can be exhaled after a full inhalation and is calculated from IRV, ERV, and TV.

Residual volume (RV) is the amount of air left in the lungs after a maximum exhalation. Total lung capacity (TLC) is the amount of air in the lungs after a maximum inhalation, or all the air that the lungs can hold. **Figure 1** illustrates the relationships among the different lung volume measurements.

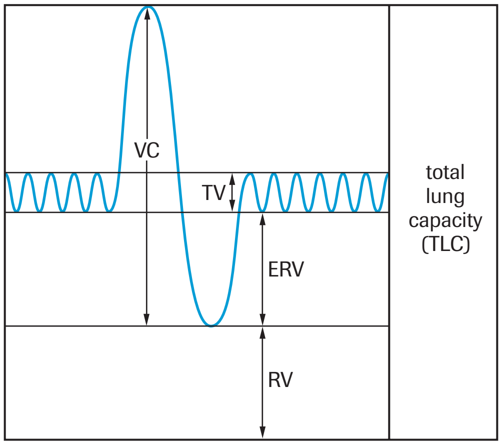

Figure 1
Lung volumes

Materials

respirometer with disposable mouthpieces

Procedure

1. Set the gauge to zero before you place a new, unused mouthpiece in the respirometer.
2. Be careful not to inhale at any time through the mouthpiece. Develop a regular, relaxed breathing pattern so you will obtain accurate results. After inhaling normally, place the mouthpiece attached to the respirometer in your mouth and exhale normally. Read the gauge on the respirometer. Record the volume exhaled as tidal volume.
3. Reset the respirometer to zero. Inhale normally, then place the mouthpiece attached to the respirometer in your mouth and exhale normally. Read the gauge on the respirometer and then exhale forcibly. Record the difference as expiratory reserve volume.
4. Reset the respirometer to zero. Inhale as much air as possible and then exhale for as long as you can into the respirometer. Read the gauge on the respirometer. Record the value as vital capacity.
5. Repeat Steps 1 to 4 for two more trials, without changing the mouthpiece.

Analysis and Evaluation

(a) Determine your inspiratory reserve volume by using the following formula:

$$VC = IRV + ERV + TV$$

(b) Using the above formula, indicate where IRV would be in **Figure 1**.

Synthesis

(c) Predict how the tidal volume and vital capacity of a marathon runner might differ from that of the average Canadian.

(d) How might bronchitis affect your expiratory reserve volume? Provide your reasons.

(e) Predict how the respiratory volumes collected for a person with emphysema would differ from those you collected.

INVESTIGATION 9.2

The Effects of Exercise on Lung Volume

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

The total lung capacity of fully grown, healthy lungs is about 5 L. However, a person normally inhales and exhales only about 0.5 L. Various factors can affect the lung volume of a single breath. In this investigation, you will design ways to test the effects of exercise on lung volume during one inhalation and exhalation.

Purpose

To determine how exercise affects lung volume during a single breath

Do not perform this activity if you are not allowed to participate in physical education classes.

Design

Design a controlled experiment that includes the following:

- a prediction and a hypothesis
- the manipulated, responding, and fixed variables
- a step-by-step description of the procedure
- a list of safety precautions
- a table to record observations

Submit your design to your teacher for approval. Then, carry out your investigation.

Analysis

(a) State how exercise affects lung volume.

Evaluation

(b) Was your prediction correct? Was your hypothesis supported?

(c) Describe any problems in carrying out the procedure.

(d) Suggest ways to improve your current design.

(e) If you were to repeat this experiment, what new factors would you investigate? Write a brief description of the new procedure.

INVESTIGATION 9.3

The Effects of Muscle Activity on Body Temperature

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Liquid crystals can be used to measure changes in body temperature. ATP supplies muscles with energy. However, some of the ATP is converted to thermal energy, which increases body temperature.

Purpose

To investigate the relationship between muscle activity and thermal energy

Do not perform this activity if you are not allowed to participate in physical education classes.

Design

Design an experiment to show the relationship between muscle activity and thermal energy. You may want to use a thermometer to calibrate the liquid crystal colours.

- Identify the controlled variables, manipulated variable, and responding variable.
- Write a prediction and a hypothesis for the experiment.
- Create a step-by-step procedure that includes any safety precautions.

Present your design to your teacher for approval. Then, conduct your experiment.

Complete an analysis and evaluation of your experiment. Communicate your results in a written report.

(a) Present your data in tables and graphically if appropriate.

(b) Present conclusions based on the data collected.

Evaluation

(c) Evaluate your experimental design.

Chapter 9 SUMMARY

Outcomes

Knowledge

- identify the principal structures of the respiratory systems, i.e., nasal passages, pharynx, larynx, epiglottis, trachea, bronchi, bronchioles, alveoli, diaphragm, rib muscles, pleural membranes (9.1)
- explain how gases and heat are exchanged between the human organism and its environment, i.e., mechanism of breathing, gas exchange, removal of foreign material (9.2, 9.3)
- explain how the motor system supports body functions, referencing smooth, cardiac, and striated muscle, i.e., digestive, circulatory, respiratory, excretory, and locomotory (9.4)
- describe, in general, the action of actin and myosin in muscle contraction and heat production (9.4)

STS

- explain that the goal of technology is to provide solutions to practical problems (9.2, 9.3, 9.4)
- explain that the products of technology are devices, systems, and processes that meet given needs; however, these products cannot solve all problems (9.3, 9.4)
- explain that concepts, models, and theories are often used in interpreting and explaining observations, and in predicting future observations (9.4)

Skills

- ask questions and plan investigations (9.1, 9.3, 9.4)
- conduct investigations and gather and record data and information (9.1, 9.3) and by identifying smooth, cardiac, and striated muscle tissue under magnification (9.4)
- analyze data and apply mathematical and conceptual models (9.1, 9.3, 9.4)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

9.1

breathing
respiratory membrane
respiration
trachea
cilia
epiglottis
larynx
bronchi
bronchiole
alveoli
pleural membrane
diaphragm
intercostal muscle

9.2

hemoglobin
oxyhemoglobin
carbonic anhydrase
buffer

9.3

chemoreceptor
bronchitis
emphysema
bronchial asthma

9.4

cardiac muscle
smooth muscle
skeletal muscle
tendon
antagonistic muscles
flexor
extensor
sarcolemma
myofilament
creatine phosphate
summation
tetanus

MAKE a summary

1. Create a flow chart or diagram that shows how the respiratory system exchanges matter and energy with the environment. Label the diagram with as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 9
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. NR The following structures are involved in respiration:
1. muscle cell
2. bronchiole
3. capillary
4. trachea

List these structures in the order in which oxygen reaches them during respiration. (Record all four digits of your answer.)

2. An increase in breathing rate is caused by
A. elevated levels of blood oxygen
B. elevated levels of blood carbon dioxide
C. reduced levels of blood carbon dioxide
D. reduced levels of blood carbon monoxide

Use the following information to answer questions 3 and 4.

Changes in the partial pressure of gases in the blood were monitored at 1-second intervals and then graphed (**Figure 1**).

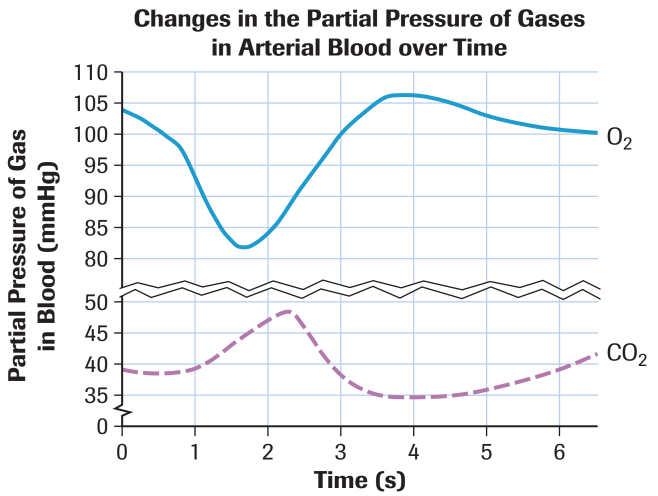

Figure 1

3. Select the time at which the chemoreceptors in the medulla will receive a message to initiate breathing movements.
A. 1.6 s
B. 2.2 s
C. 3.5 s
D. 4.0 s

4. Identify the time that would immediately follow a breathing movement and the reason why.
A. 1.7 s, because oxygen and carbon dioxide leave the blood
B. 3.5 s, because oxygen is entering the blood and carbon dioxide is leaving the blood
C. 4.5 s, because oxygen and carbon dioxide enter the blood
D. 4.5 s, because oxygen is entering the blood and carbon dioxide is leaving the blood

5. Identify the factors that would increase the delivery of oxygen to the tissues.
A. high blood volume and high altitude
B. low blood volume and high altitude
C. high hemoglobin and low altitude
D. low hemoglobin and low altitude

6. Identify the diagram in **Figure 2** that correctly depicts a contracted muscle fibre.

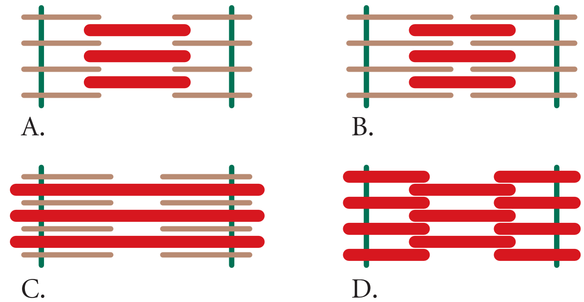

Figure 2

Use the following information to answer questions 7 and 8.

Different types of athletes have different amounts of type IIa and type IIx muscle fibres.

1. sprinter
2. marathon runner
3. average active person
4. extreme endurance athlete

7. NR List all of the given athletes in the order of increasing amount of type IIa and type IIx muscle fibres. (Record all four digits of your answer.)

8. NR List all of the given athletes in the order of their increasing oxygen demand. (Record all four digits of your answer.)

Part 2

Use the following information to answer questions 9 to 11.

Figure 3 shows the components of the human respiratory system.

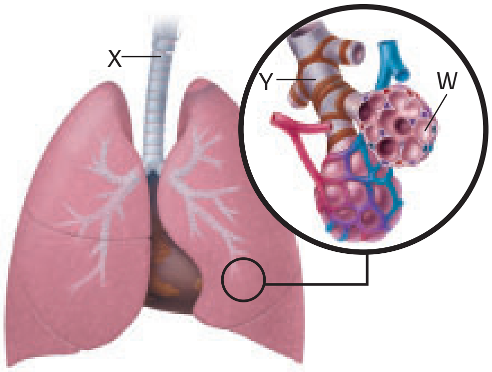

Figure 3

9. **Identify** the structures labelled W, X, and Y in **Figure 3**, and **describe** the function of each. DE

10. **Identify** the structure(s) in **Figure 3** that have cartilaginous bands. DE

11. The inflammation or restriction of airflow in one of the structures in **Figure 3** is associated with asthma. **Identify** this structure. DE

12. **Describe** the pressure changes that occur during inhalation and exhalation.

Use the following information to answer questions 13 to 15.

The composition of air was analyzed from inhaled and exhaled air (**Table 1**).

Table 1 Composition of Inhaled and Exhaled Air

Air component	Inhaled air (%)	Exhaled air (%)
oxygen	20.71	14.60
carbon dioxide	0.41	4.00
water	1.25	5.90
nitrogen	78.00	75.50

13. **Explain** why more water is found in exhaled air. DE

14. **Explain** the difference in oxygen levels in inhaled and exhaled air. DE

15. If nitrogen is not used by the cells of the body, **explain** the different composition between inhaled and exhaled air. DE

16. Changes in the partial pressure of gases in arterial blood were monitored over time as a subject began to perform light exercise (**Figure 1**, previous page).
- (a) At which time would the breathing rate likely be greatest? **Justify** your answer.
- (b) **Predict** when the subject began exercising. **Describe** your reasons.
- (c) When would the breathing rate return to normal? **Explain**.

17. According to the data shown in **Figure 4**, **identify** which hemoglobin is more effective at absorbing oxygen. **Describe** the adaptive advantage that is provided by hemoglobin that allows it to combine readily with oxygen.

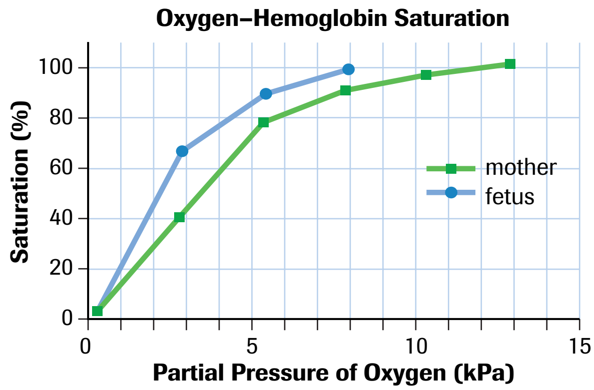

Figure 4

18. Cigarette smoke has the following effects:
- There is destruction of many of the cilia that line the bronchi and bronchioles.
- There is a buildup of mucus along the walls of the bronchioles. This reduces their interior diameter.
- There is an increase in blood pressure that causes the rupturing of the walls of some of the alveoli.

Refer to each of the effects listed above. **Describe** specific ways in which the normal functioning of the respiratory tract is altered by smoking tobacco.

19. **How** does the fact that muscles shorten when excited help support the sliding filament theory of muscle contraction?

20. **Why** does the condition of rigor mortis support the theory that ATP is required for muscle relaxation?

21. **Explain** how the motor system supports
- (a) the digestive system
- (b) the respiratory system

Extension

22. Allan Becker of the University of Manitoba studies dogs to learn more about how asthma works in people. Research how allergies have been linked with asthma. **Describe** the advantages and disadvantages of using modelling experiments on dogs.

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